LCWS 2018
(not a) Summary
Vision (??) Talk

or

The Road from Higgs Discovery to Higgs Factory?

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ICFA Chair

Opinions expressed in this presentation are my own. They don't represent the opinions or strategies of anyone who really counts!

Vision ?

- My drivers…
  - *Particle Physics for discovery and improved understanding of nature's fundamentals.*
  - *Particle Physics to inspire the best young minds in scientific and technical innovation*
  - *Particle Physics as an essential motivator in technology, including its applications*
  - *Particle Physics is exemplary in international cooperation and exchange.*

The Search for Deeper Understanding Drives Our Field

- Measurement and Discovery
  - *Gaps filled*
  - *Questions raised*
  - *Critical Physics Priority Setting*
- Requirements of Next Facility
  - *Critical Facility Priority Setting*
  - *Technology, Resource and Partnering Requirements?*

Many Questions Remain…

eg. Chris Quigg “Dream Machines”

Rev. Acc. Sci. and Techn. 1 (2018) 1-9.

1. ***Beyond the Higgs-boson discovery***
   - more Higgs? additional EWS breaking? other sources of fermion mass? coupling proportional to mass? …
2. ***More new physics on the TeV scale and beyond?***
   - quark/lepton compositeness? DM? Vacuum Energy? …
3. ***Flavour: the problem of identity***
   - RH CC? additional EW gauge bosons? LFV? why 3 families?
4. ***Some outstanding questions in neutrino physics***
   - mass hierarchy? absolute mass? CP violation in neutron oscillations? Majorana particles? sterile neutrinos? …

- ***What new facility would you choose!!***

Richness of Our Facilities

1. Non-Accelerator Particle Physics

- *Cosmic Rays*
  - Neutrinos, Gamma-rays, UHE nuclei
- *Reactor Neutrinos*
- *Dark Matter Searches*
  - (WIMPS, Axions, WISPs…)
- *Double Beta-decay*

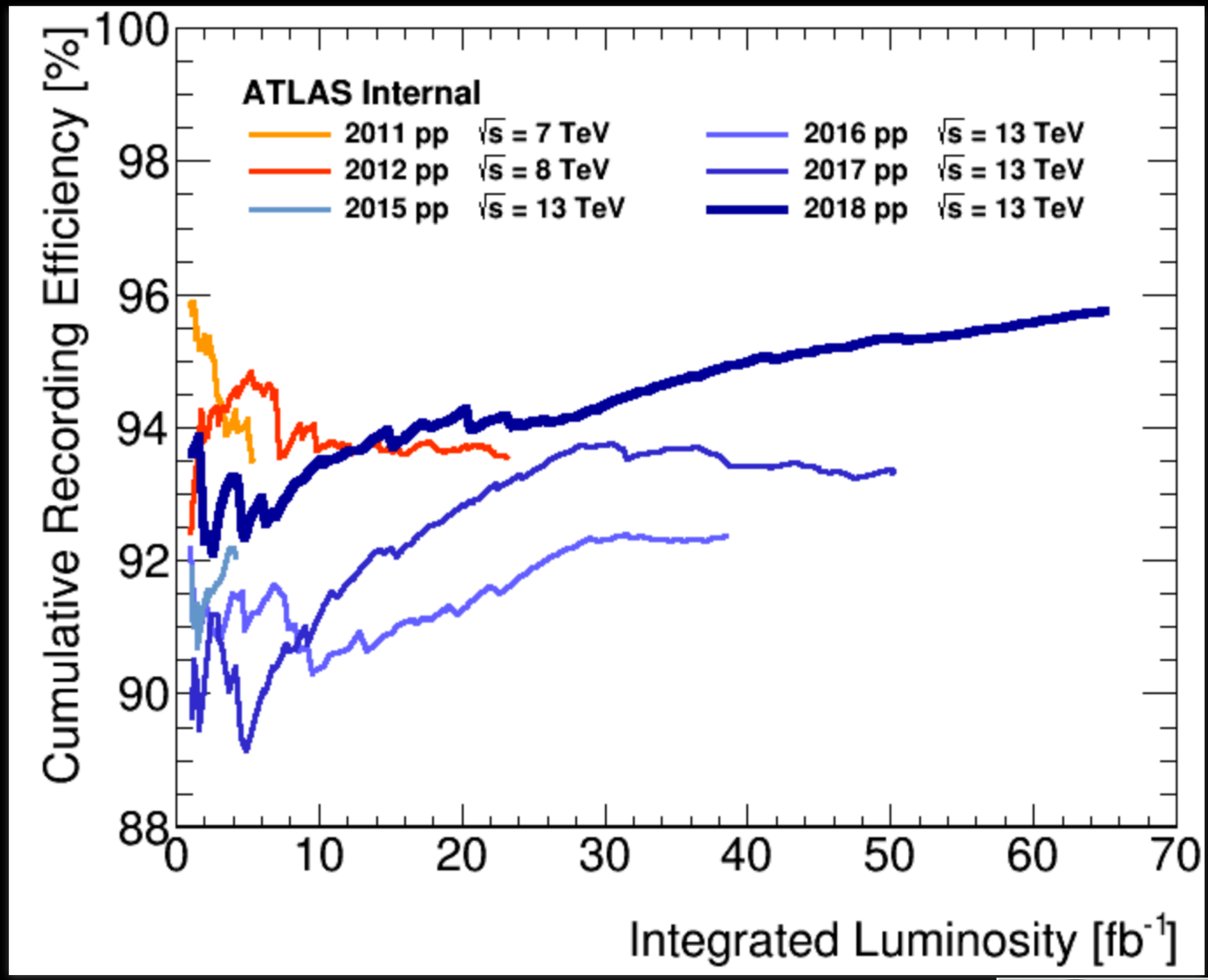
Richness of Our Facilities

2. Accelerator Particle Physics

- *Proton Colliders*
- *Heavy Ion Colliders*
- *Electron-Positron Colliders*
- *Neutrino Beams*
- *…*

Last LHC proton fill
Run 2 yesterday - Excellent Performance

Experience results in higher luminosity, better experiment efficiency



Never any shortage of options …

- Neutrino Physics
  - *DUNE/LBNF and J-Parc Hyper-K, from ~2025-26*
  - *Perhaps, perhaps muon-storage-ring neutrino source?*
- Flavour Factories
  - *Belle II, LHCb until 2023-2026?*
  - *Beyond? Giga- (or Tera-) Z as flavour source?*
- Proton Colliders
  - *LHC, HL-LHC 2026-2035*
  - *… perhaps ~30TeV HE-LHC*
  - *… perhaps, perhaps ~100TeV 100km facility - SppC, FCC-hh*
- Electron-positron Colliders
  - *ILC, CLIC … linear machines 250GeV to multi-TeV*
  - *CEPC, FCC-ee … circular 90, 160, 250, 370(?) GeV*
- Perhaps e-H collider?

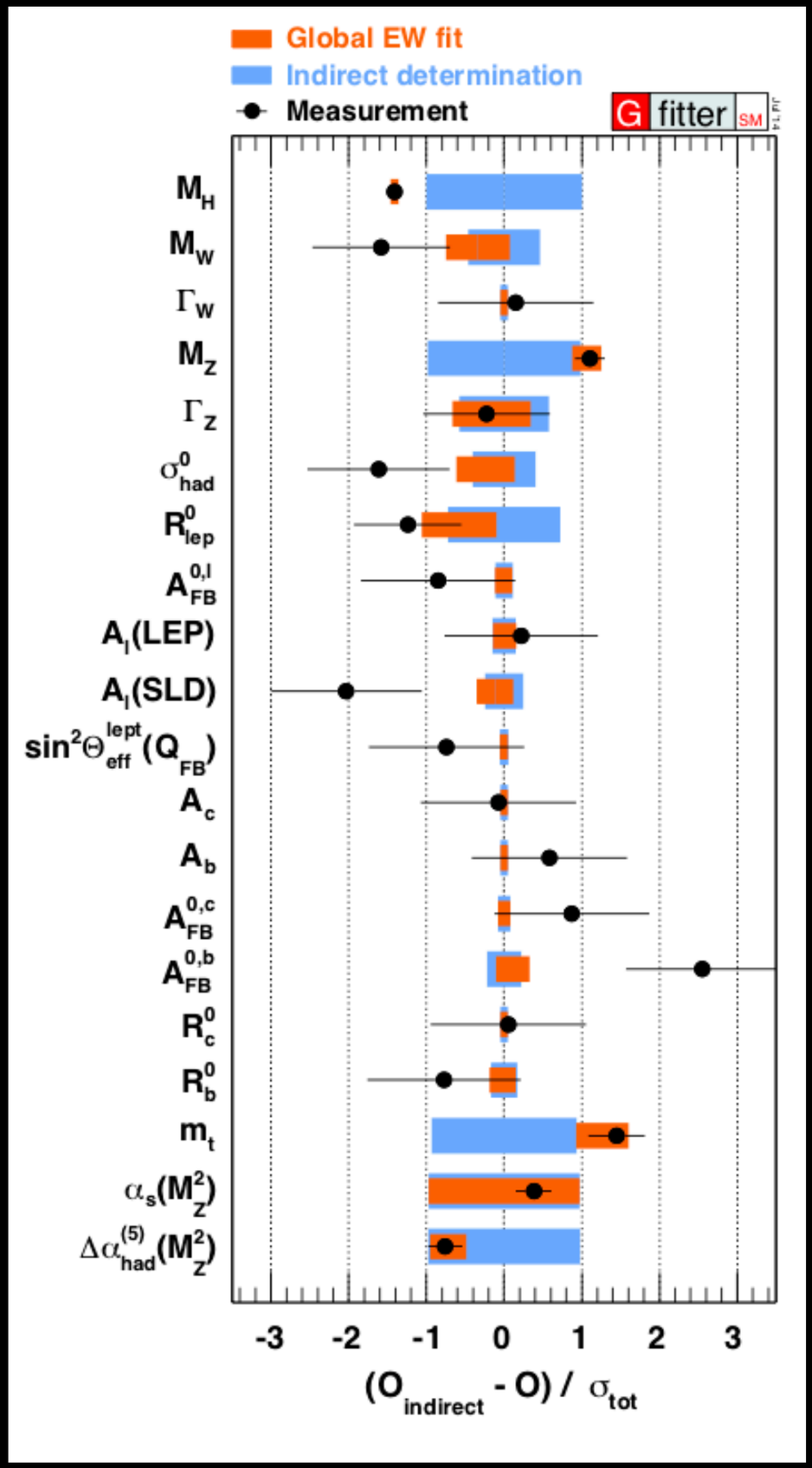
Some Lessons from History?

1. SLC and LEP: Precision Z-boson, …

- *SLC: new technology using existing facilities*
- *SLC: luminosity limit, reliability*
- *LEP: new scale (27km), new tunnel, relatively straightforward technology*
- *LEP: provided a decade of major successes*
- *SLC: groundbreaking LC, SLD: A_{LR}*

Aside:

- SLD FB asymmetry STILL important in SM fits
- The longterm benefit of polarised beams is surprising.
- Lesson (?): Dont give up on options too early



Some Lessons from History?

2. SSC and LHC: Higgs Search, …

- ***SSC: identified benefit of large radius facility!***
- ***Began as national facility:***
  - Funding continuity was not guaranteed
  - Design and Management: Cost control issues
    - *"Tunnel Visions. The Rise and Fall of the SSC",Michael Riordan, Lilljan Hoddeson and Adrienne W. Kolb University of Chicago Press, 2015*
  - International support/participation/partnering came late
- ***CERN site/experience, LEP tunnel: Success for LHC***
- ***LHC: Magnet Technology - "stretch goal"***
  - Major 2008 magnet incident highlighted vulnerability
  - Design, management, technology expertise saved LHC
- ***SSC Cancellation: US Physicists moved to LHC.***
- ***LHC: excellent example of international cooperation.***
  - Major success story

Some Lessons from History?

3. KEKB, PEPII, LHCb

- *Rich, successful program with constructive Belle, Babar competition*
  - Both machines built at established laboratories
- *SuperB Factory demise*
  - Strong Babar migration to SuperKEKB/Belle II
- *Complementarity of Belle II & LHCb remains*

(TRISTAN - physics desert, but led to KEKB, SuperKEKB)

ALL MAJOR DECISIONS MUST BE BY "INTERNATIONAL CONSENSUS"

- Difficult but we have generally succeeded.
  - *Even advising each others' nations/regions in their priority setting and decisions*
- Facilities getting larger
  - *Required Resources Very Large*
  - *Timescales Very Long*
- Our Field needs to be even better organised

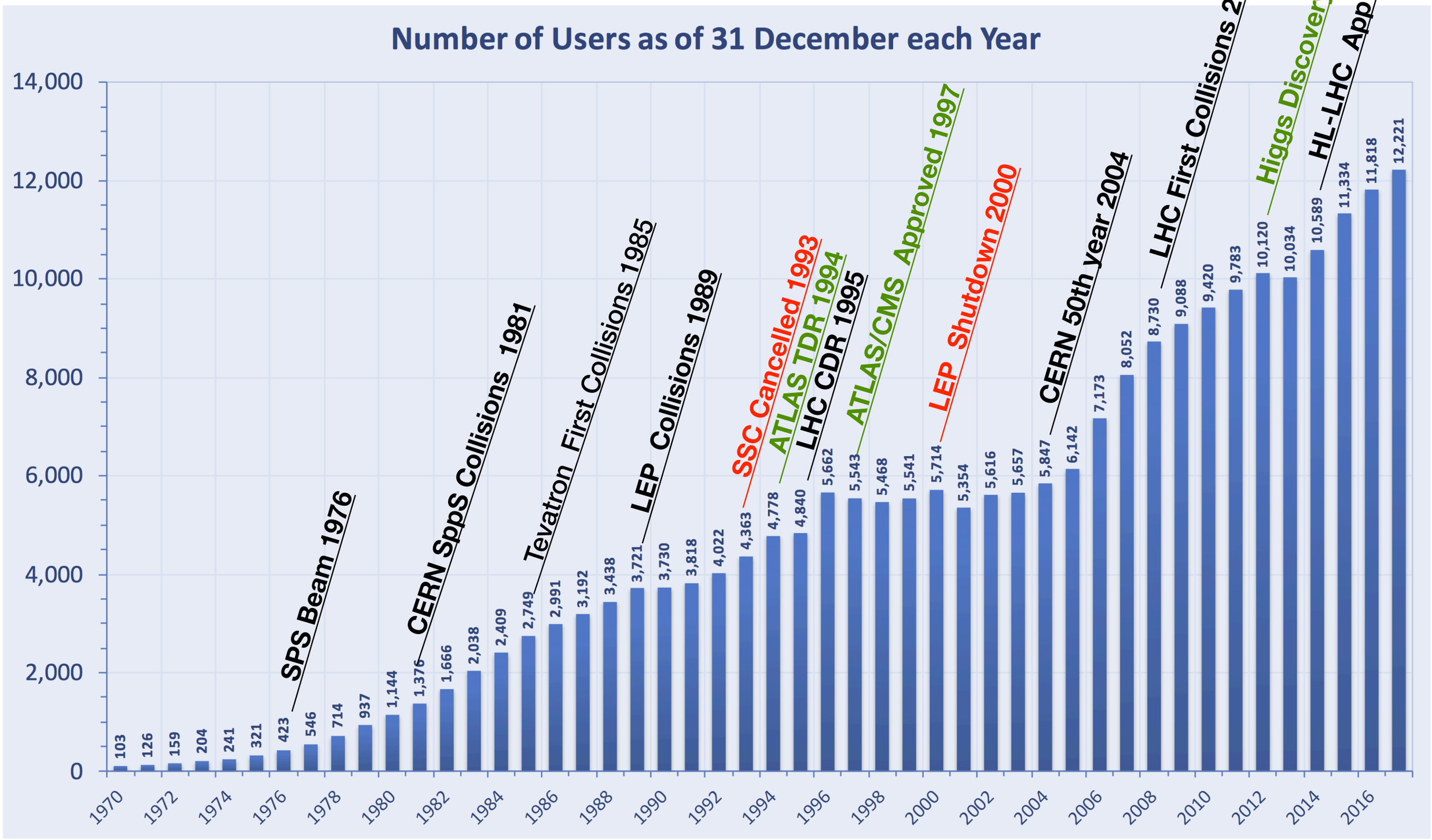
Warning (perhaps!)

- The LHC is the only successful $Multi-Billion HEP project to date. That was with the CERN budget at its base, and sited at CERN.
  - *And significant international contributions sought early*
- Crossing the threshold to Billions, even though evolutionary, crosses a psychological boundary.
  - *It gets noticed!*
- The SSC showed that governments want much stronger control over multi-billion dollar projects.
  - *Needs managing. Kept in physicists' hands*
- The next frontier machine needs major commitment to political support, and when (if) supported will need to be very well managed for the future of our field.

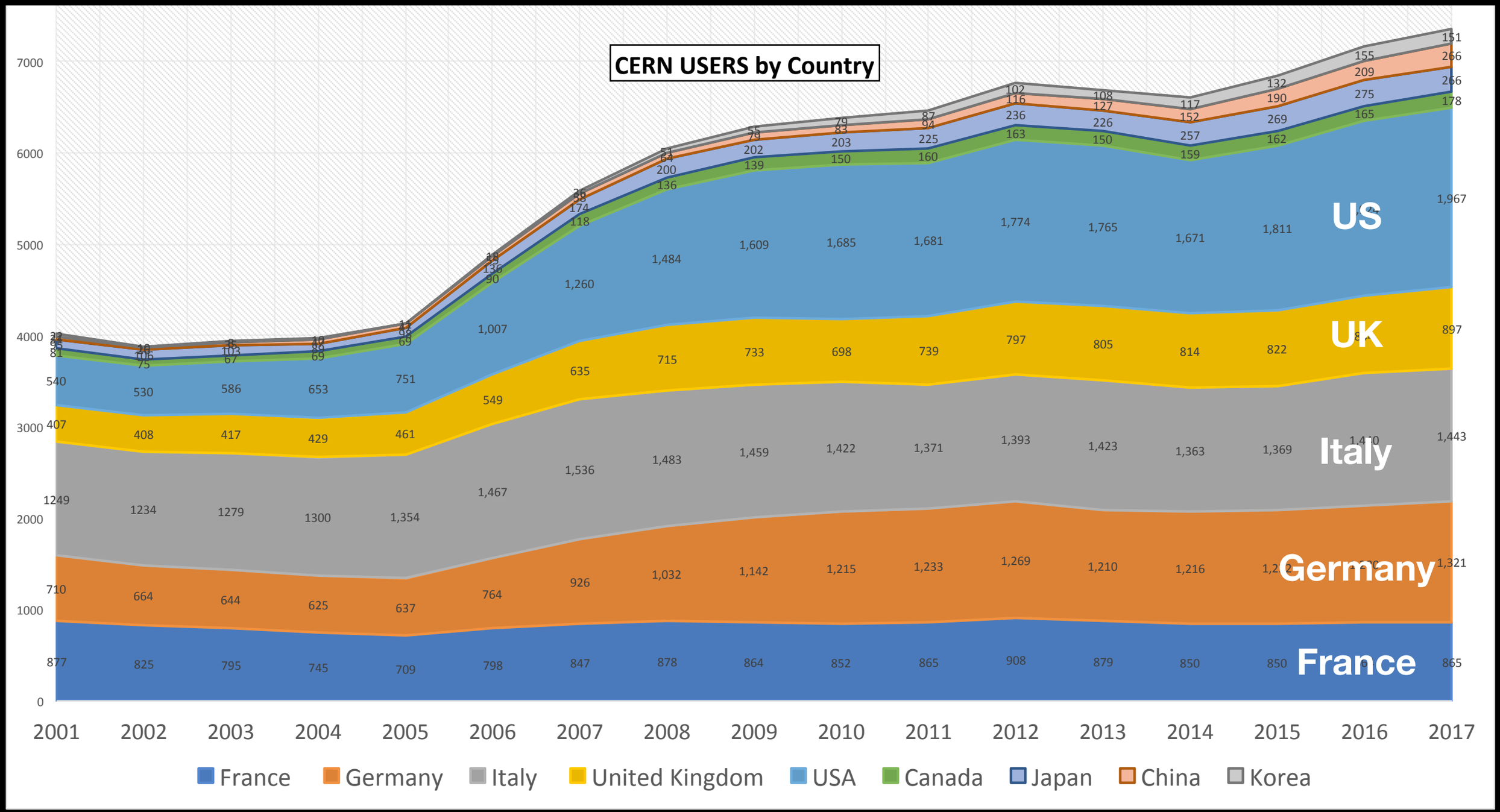
HEP is International

- Nature has Cycles
- International Roles Cycle too:
  - *Economic strength*
  - *Political Will*
  - *Science and Technology Focus*
- Embrace Change
- Exploit Opportunity
- Create Capacity
- Consensus (Compromise??) required

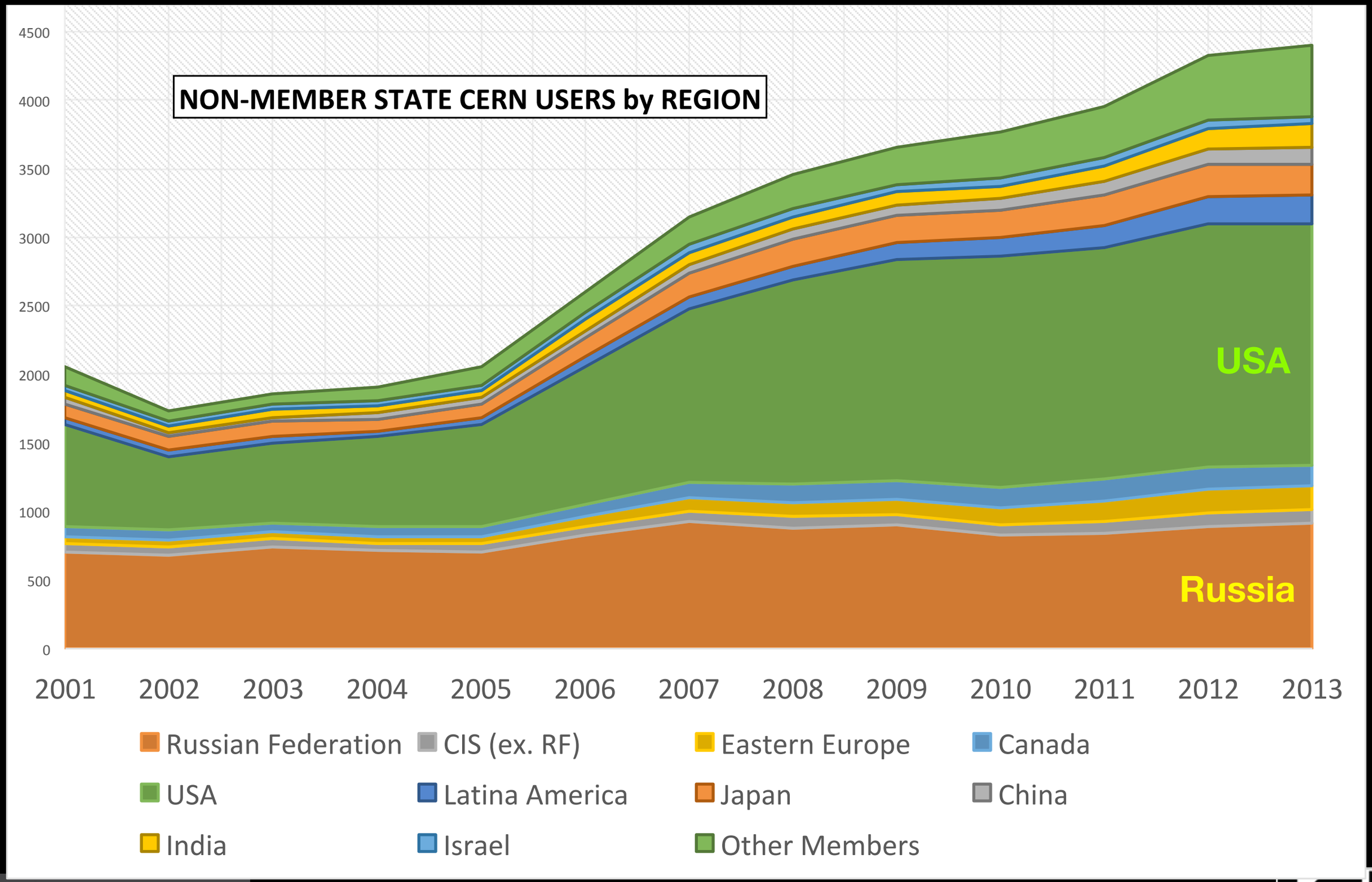
CERN Users


Number of Users as of 31 December each Year
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
SPS Beam 1976
CERN SppS Collisions 1981
Tevatron First Collisions 1985
LEP Collisions 1989
SSC Cancelled 1993
ATLAS TDR 1994
LHC CDR 1995
ATLAS/CMS Approved 1997
LEP Shutdown 2000
CERN 50th year 2004
LHC First Collisions 2008
Higgs Discovery 2012
HL-LHC App'l 2014
103
126
159
204
241
321
423
546
714
937
1,144
1,376
1,666
2,038
2,409
2,749
2,991
3,192
3,438
3,721
3,730
3,818
4,022
4,363
4,778
4,840
5,662
5,543
5,468
5,541
5,714
5,354
5,616
5,657
5,847
6,142
7,173
8,052
8,730
9,088
9,420
9,783
10,120
10,034
10,589
11,334
11,818
12,221

CERN User Snapshot



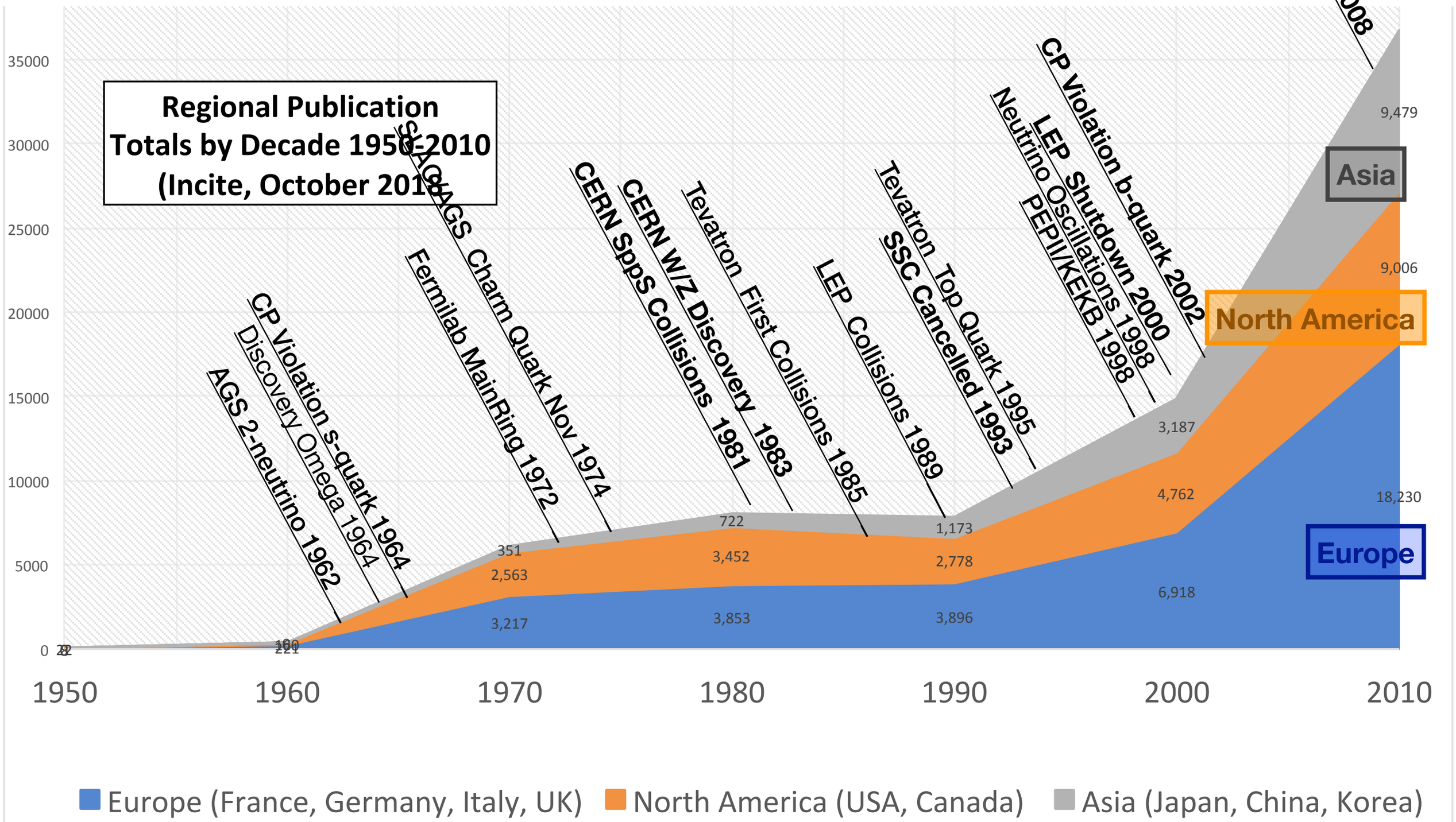
Non-Member State CERN Users



HEP Expt'l Publications

- All Regions Benefit -

(Inspire, October 2018)



International Focus is Flexible

- History shows that our community will go where the facilities are built
- Our community leads to improved outcomes at the facilities/ laboratories to where they go.
- The growth seen since the beginning of LHC era can be maintained with expanded facilities

Dream Scenario?

- HL-LHC (2026-2030's) - Approved; Improved searches
  - *HE-LHC (28-35 TeV) …from ~2040-2050 and beyond??*
  - *(Is FCC over-reach at current moment?)*
- ILC250 - Higgs Factory extendable to Top and Multi-Higgs
  - *Capability to extend to 380GeV and 500GeV?*
  - *?? Keep longer term capacity for CLIC style 2-beam acceleration >1 TeV ??*
  - *??? Longer, longer term capacity for addition of plasma or laser wake-field sectors???*
- CEPC - Precision SM, Higgs Factory
  - *Giga- (Tera-)Z, W+W-, Higgs Factory 250 GeV*
  - *Longer term capacity for Top physics?*
  - *Longer, longer term capacity for protons in tunnel ??*

Justification (???)

- CERN is a critical foundation for the field.
  - *Must be maintained.*
  - *At least a 3-decade program at the energy frontier foreseen!*
  - *Uniquely provides support for a large range of activities on site and internationally*
- CERN leads in high energy proton capability
  - *HL-LHC schedule allows(??) ILC Support*
  - *Large group of SC Magnet Specialists*
  - *Decades of experience*
- Maintain High Energy Proton Collider for direct discovery
  - *HE-LHC (?)*
  - *Is this really the moment for serious resource discussions for FCC-hh in Europe?*

Justification (???)

- ILC: linear machine has energy expansion capacity
  - *Initially: 250GeV Higgs factory (ZH)*
  - *Mature design, community well prepared for next step*
  - *SC-RF progress - 380GeV (maybe 500GeV) possible*
- China new, major player in HEP
  - *CEPC would come with new (Chinese) resources*
- Circular machine:
  - ***Excellent Luminosity at low energy***
    - Giga-Z, W+W- production.
    - Precision SM
  - ***Overlap with ILC at 250-370GeV***
    - Redundancy, systematics check
    - Removes need for push-pull detectors at ILC (??)
  - ***Fixed radius - maximum energy is wall-power limited!***

Justification (???)

- Strong US Support
  - *Key players in SC RF development*
  - *Strong detector/physics commitment*
- Major US commitments (DUNE/LBNF) compatible with ILC Schedule
- Japan HEP community strongly supportive of the ILC
- Many preparations are advanced
  - *TDR, SC/RF, Klystron Efficiency, Site selection, ….*
- Major Japan commitments (SuerKEKB/BelleII, J-Parc/HyperK) compatible with ILC Schedule

… and …

- CLIC physics community could join ILC community.
  - *(CLIC accelerator R&D should continue)*
- FCC-ee physics community could join CEPC
- High energy proton development remains key CERN program

US Support for ILC?

US Lab Support and Technology Base for major in-kind will be critical.

- *From Andy White:*
  - A survey of the US labs shows potential **contributions to the ILC250 similar to those in the 2013 report.**
  - -**Additional support would be needed for planning,** R&D, training technical staff, production ramp up etc.
  - The present and planned tasks at the labs are mainly **compatible with the anticipated ILC timeline.**
  - The development of a **detector design**, completion of a TDR, and **construction is also compatible with the ILC timeline.**

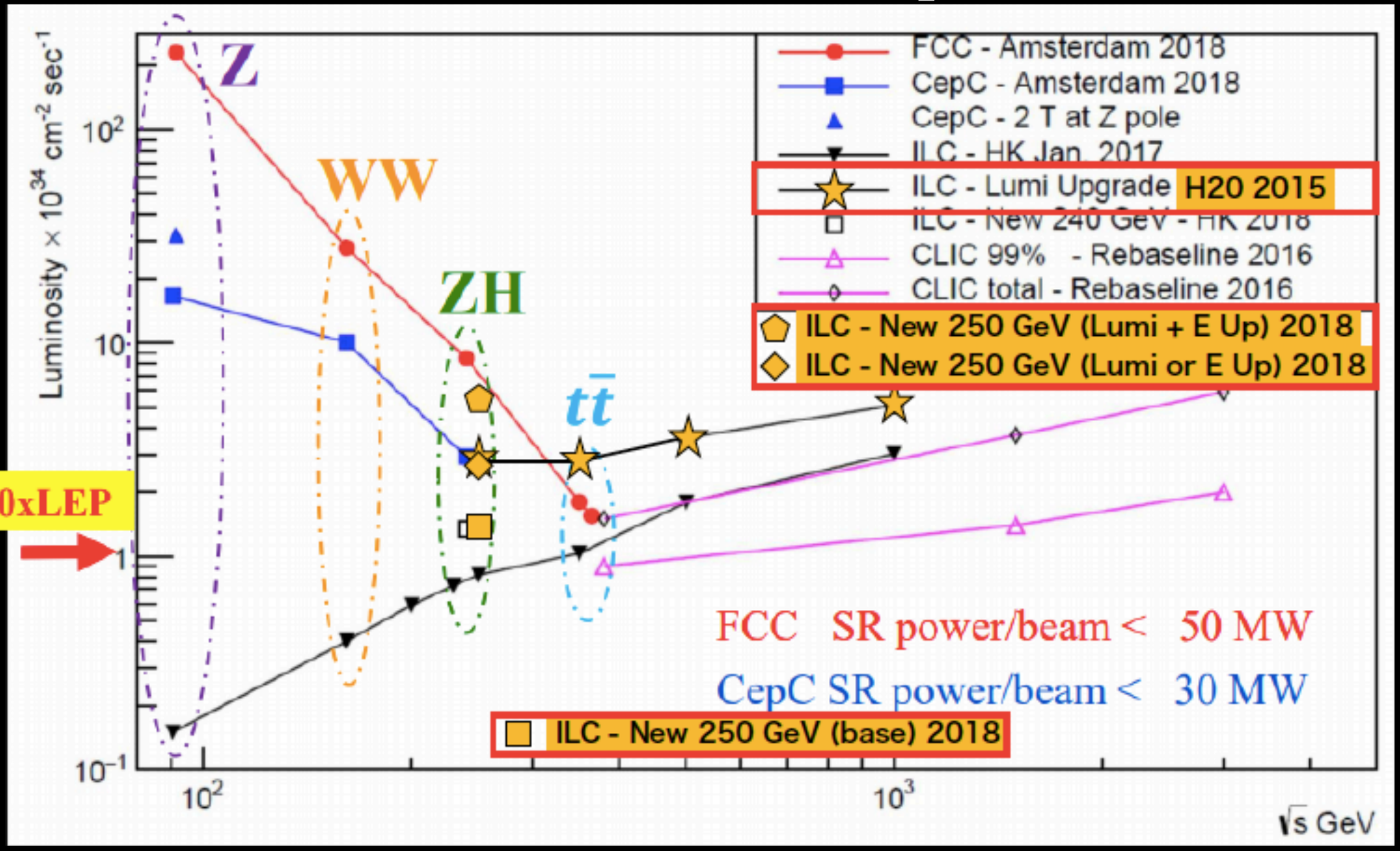
European Support for ILC?

- CERN Prosperity Essential for ILC Support
  - *For European and International Physics Community*
- Input and Outcomes from 2020 European Strategy Update are Critical
  - *ILC Support? 2013: "Europe looks forward to a proposal from Japan to discuss a possible participation" - perhaps for the 2020 Update?*
- CLIC proposal provides pressure for ILC decision
  - *Positive decision: CLIC community can work with ILC*
- Also: HL-LHC provides Higgs and BSM physics benchmark that any future machines must significantly improve upon.

Chinese Support for ILC?

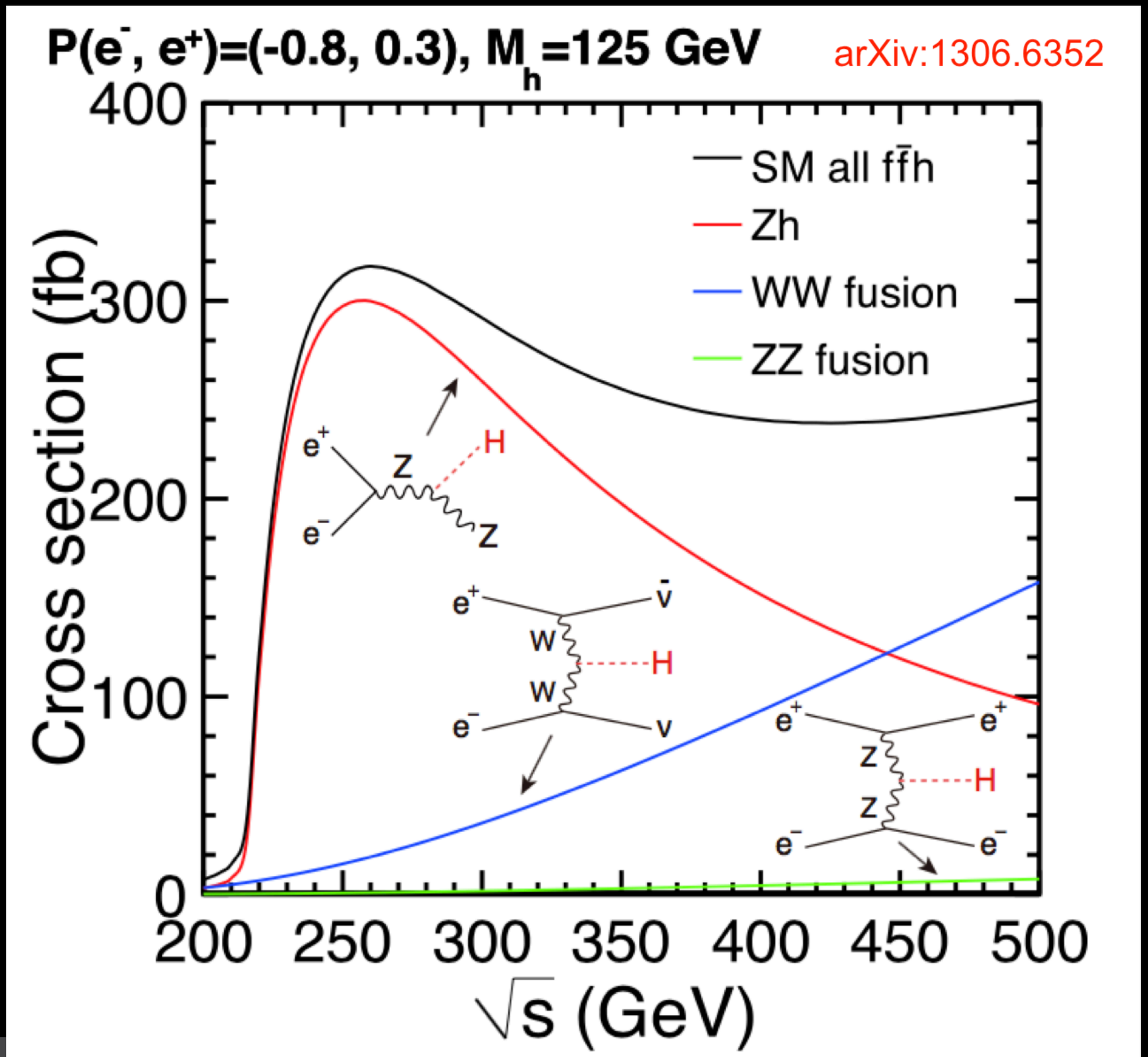
- ILC Approval seen as International vetting for 250 GeV e^+e^- CEPC
- Already developing in-kind technology such as SC Cavities for ILC participation
- ILC as example of Internationalisation of Asian science

e^+e^- Lumi Comparison

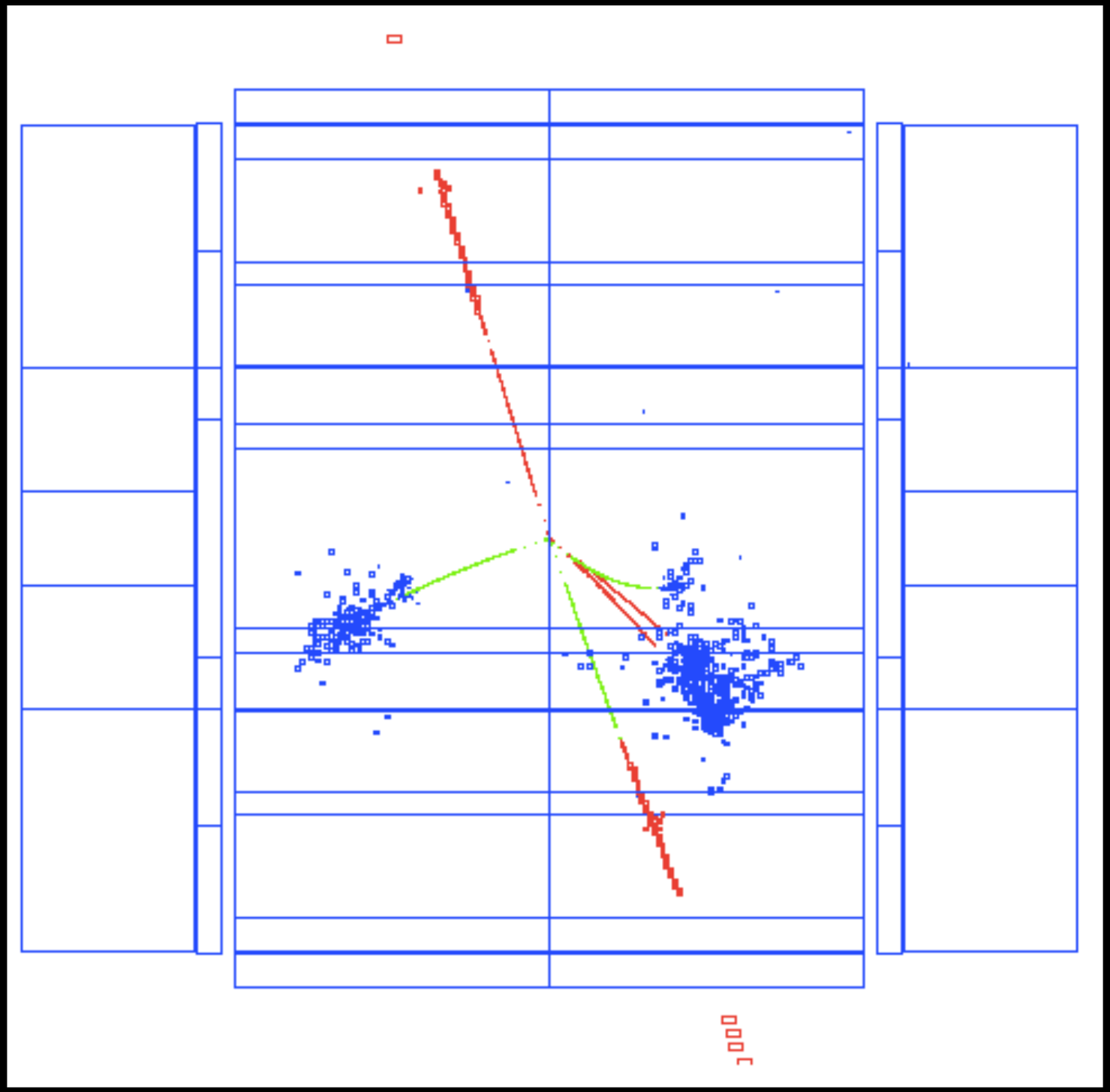


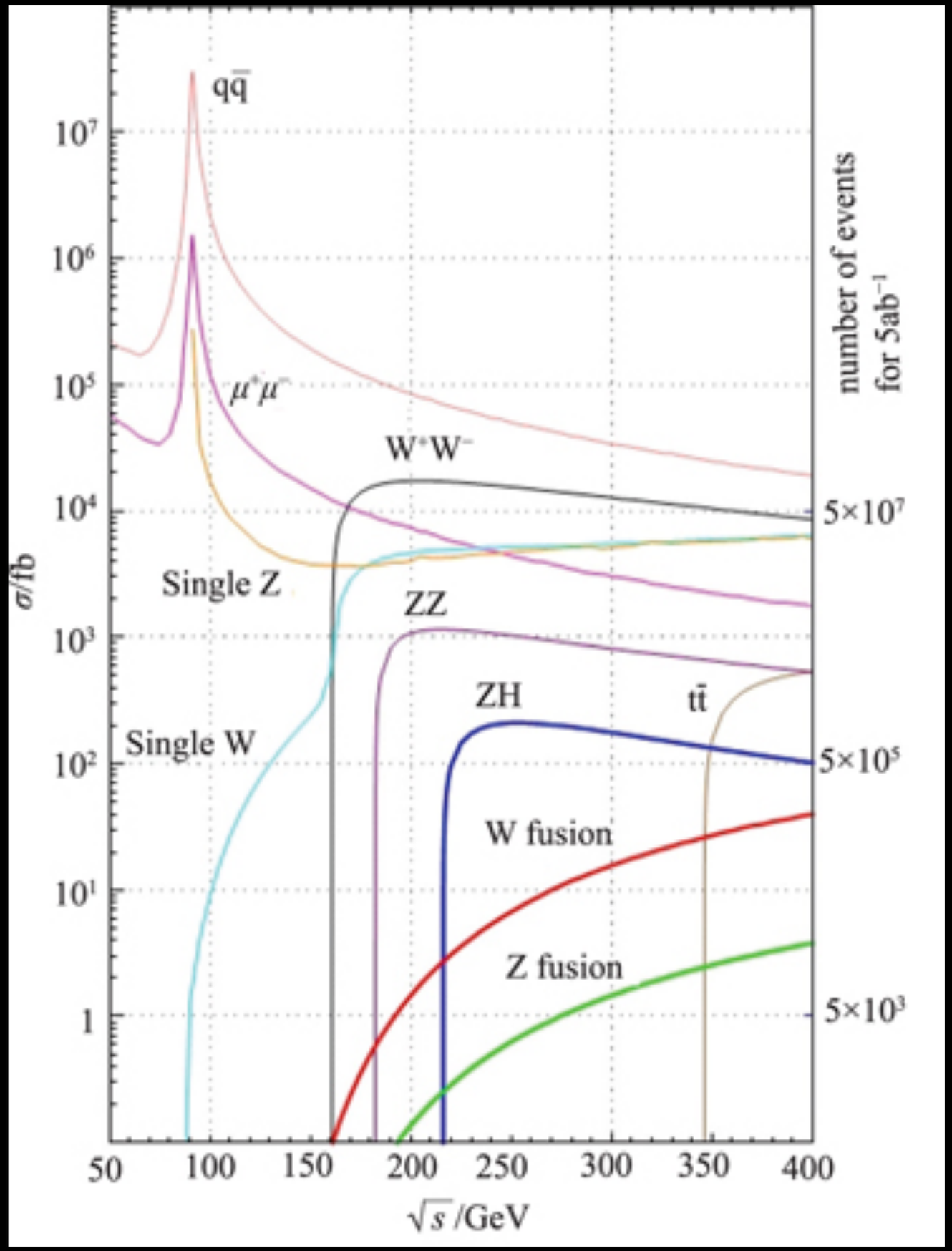
- Original Plot, F. Bedeschi , CEPC Workshop, Rome, May 2018
- Updates Private communication, Keisuke Fujii, IPNS, KEK

A few examples of the physics …

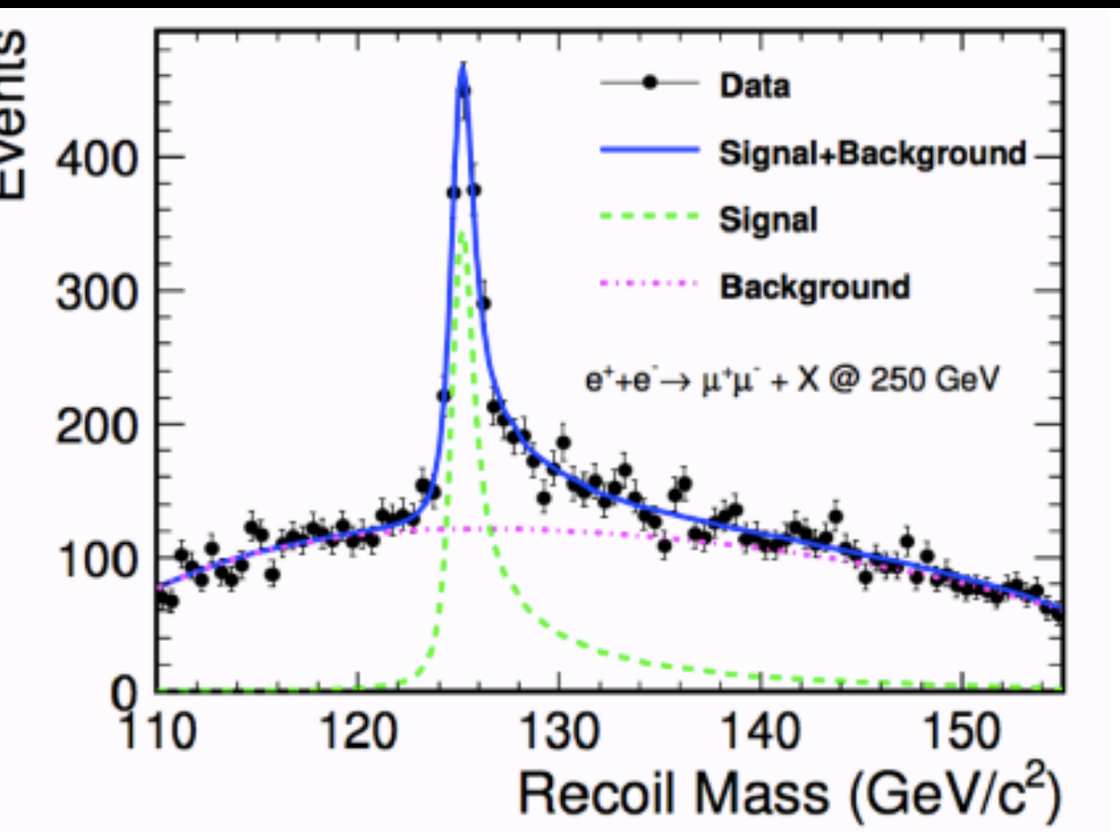

P(e⁻, e⁺)=(-0.8, 0.3), M_h=125 GeV
arXiv:1306.6352
Cross section (fb)
400
300
200
100
0
200 250 300 350 400 450 500
√s (GeV)
SM all ffh
Zh
WW fusion
ZZ fusion
e⁺
e⁻
Z
H
Z
e⁺
ν̄
W
H
W
e⁻
ν
e⁺
e⁺
Z
H
Z
e⁻
e⁻

Trigger on Z: The remainder is Higgs decay products

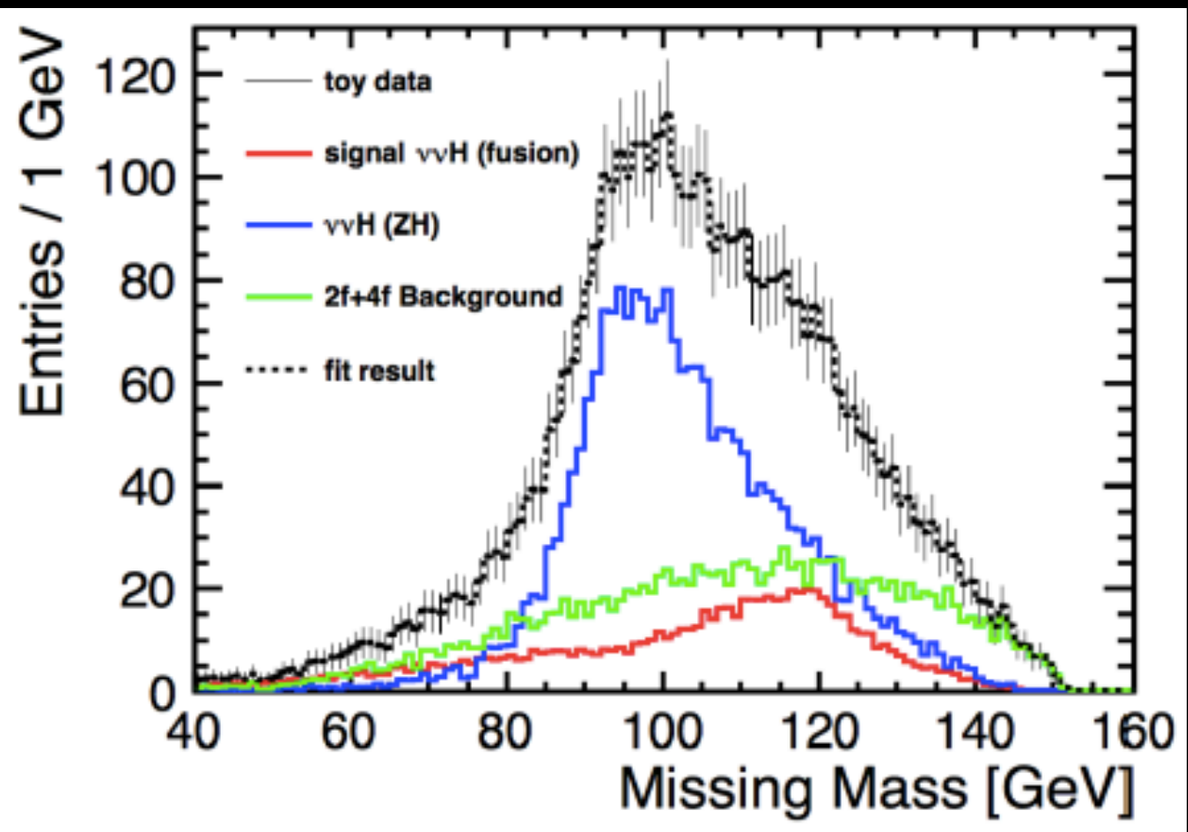



qq̄
μ⁺μ⁻
W⁺W⁻
Single Z
ZZ
ZH
tt̄
Single W
W fusion
Z fusion
σ/fb
number of events
for 5ab⁻¹
5×10⁷
5×10⁵
5×10³
10⁷
10⁶
10⁵
10⁴
10³
10²
10¹
1
50
100
150
200
250
300
350
400
√s /GeV

arXiv:1710.07621v4 [hep-ex] 7 Aug, 2018



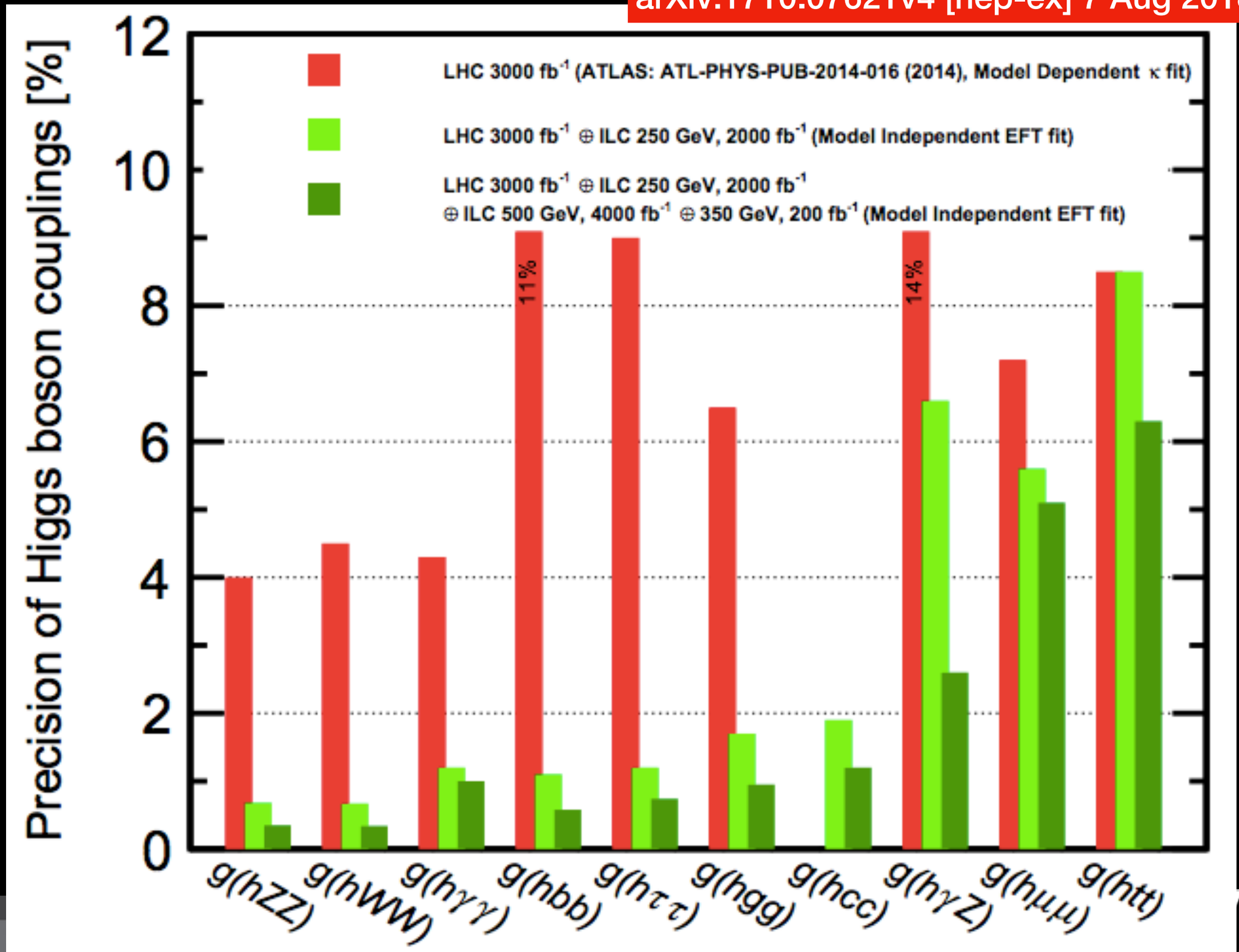
Recoil mass against
$Z \to \mu^+\mu^-$ in $e^+e^- \to Zh$



Missing mass in
$e^+e^- \to \nu\bar{\nu}h$, $h \to b\bar{b}$

Precision Higgs Couplings

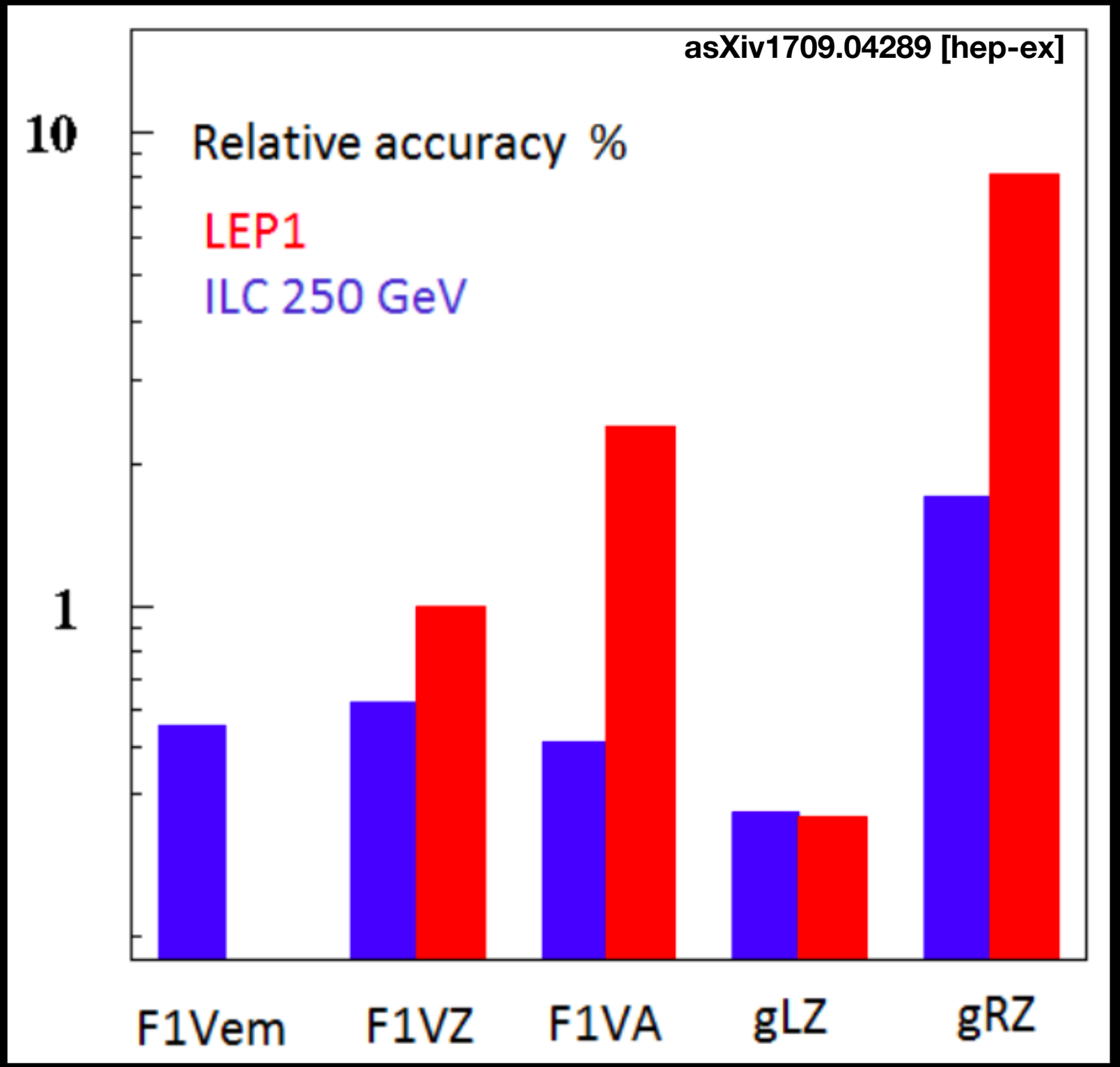
arXiv:1710.07621v4 [hep-ex] 7 Aug 2018



2-fermion production

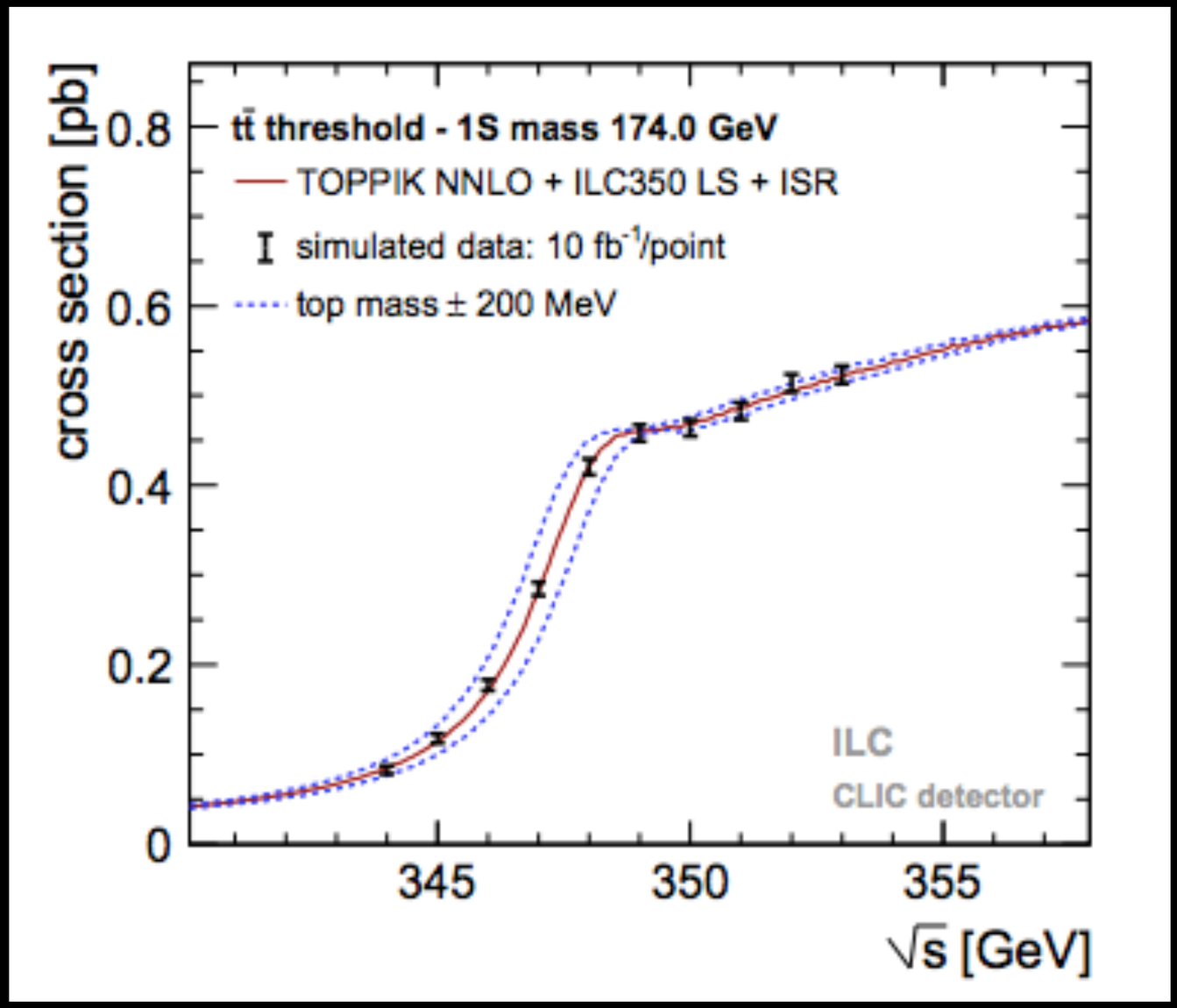
Precision E-W form factors for bb production ILC250, 500fb^{-1}

Also see M.Peskin this conference



Future Extended Energy - 350GeV

arXiv:1611.04492v1 [hep-ex] 14 Nov 2016



Far Future Extended Energy - 500GeV

ILC TDR

500GeV:
Higgs self-coupling

Figure 2.16
Relevant diagrams containing the triple Higgs coupling for the two processes: $e^+e^- \to Zhh$ (left) and $e^+e^- \to \nu_e\bar{\nu}_e hh$.

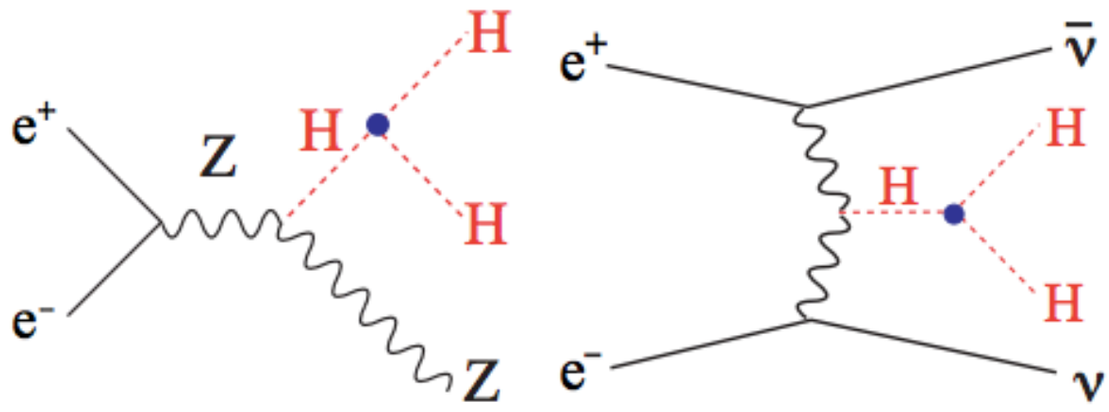
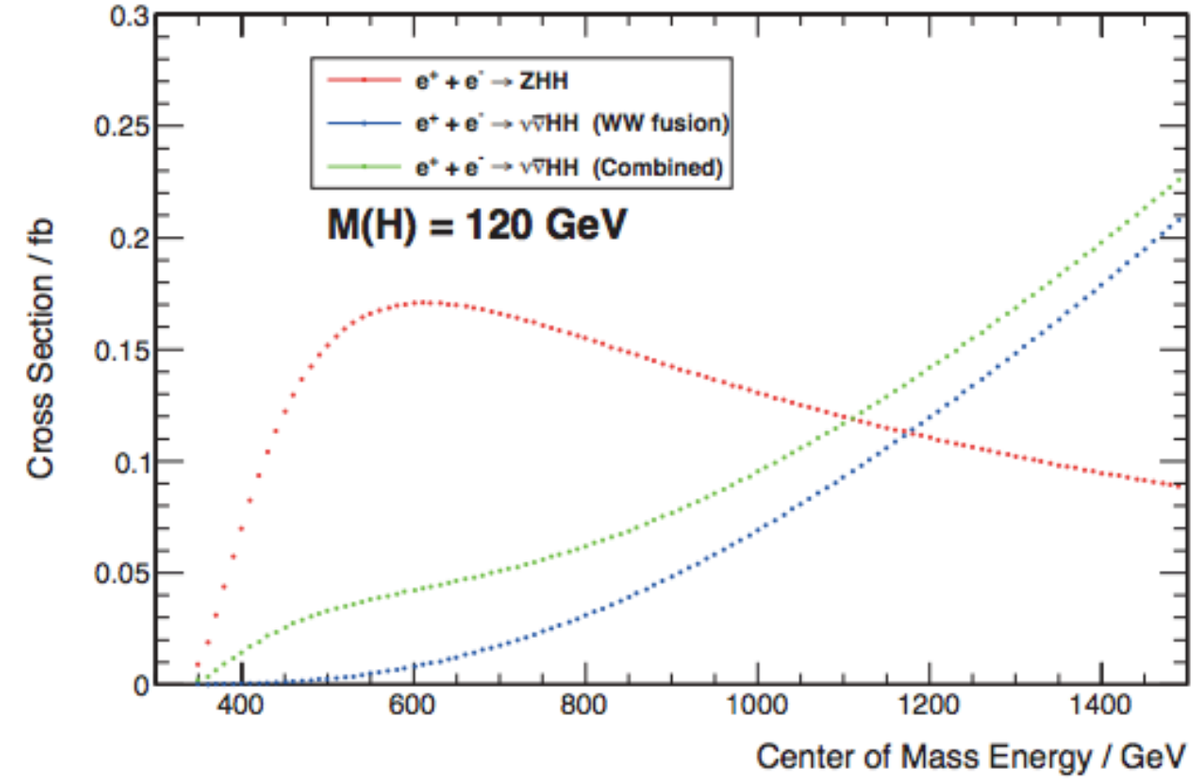
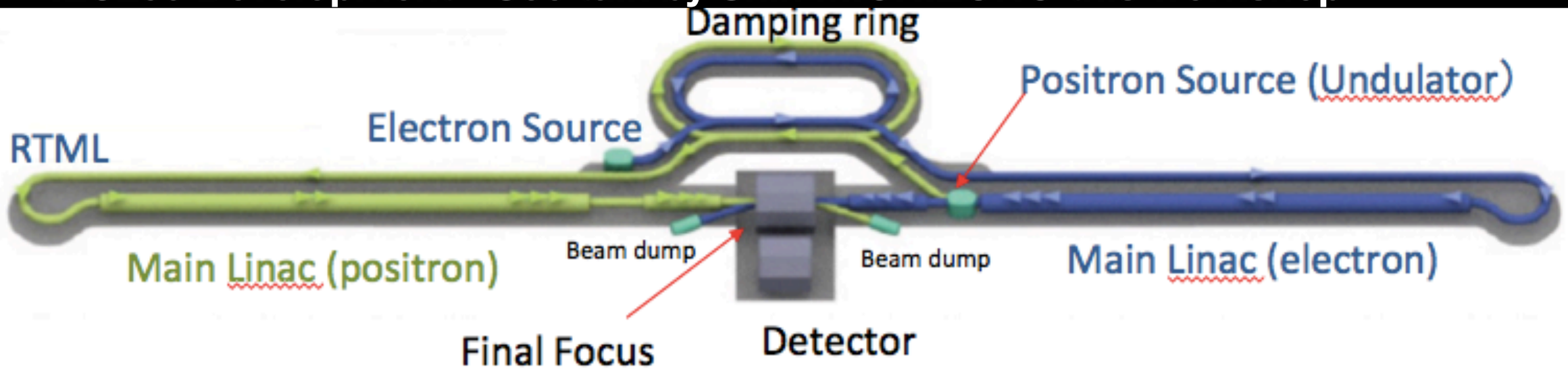


Figure 2.17
Cross sections for the two processes $e^+e^- \to Zhh$ (left) and $e^+e^- \to \nu_e\bar{\nu}_e hh$ as a function of $\sqrt{s}$ for $m_h = 120$ GeV.

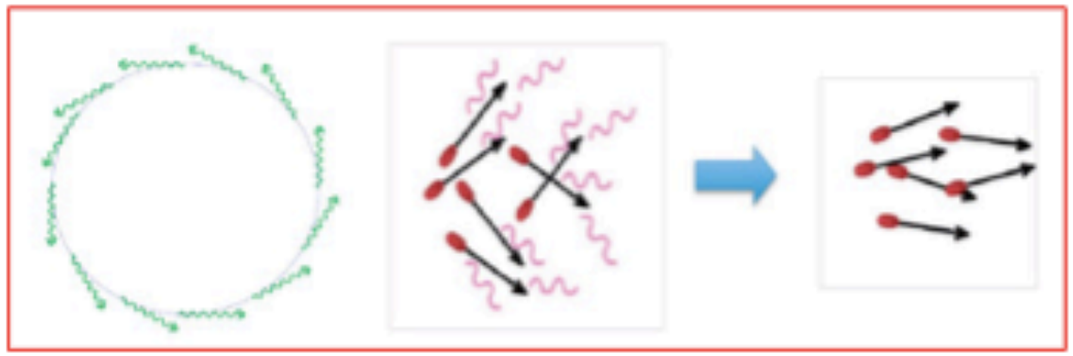


ILC250 Development - See talk by Shin MICHIZONO this workshop



Best performance by combining state-of-the-art technology

- Sources ***Electron/positron***
  - Polarized electron/positron
- High quality beam ***Damping ring***
  - Low emittance beam
    - Small-size
    - Parallel beam
- Beam Transport ***RTML***
  - Bunch compressor
- Beam acceleration ***Main linac***
  - Superconducting RF acceleration
- Beam collision ***Final focus***
  - Nano-meter beam



Low emittance beam at damping ring

1.3GHz（L-band) SRF cavity

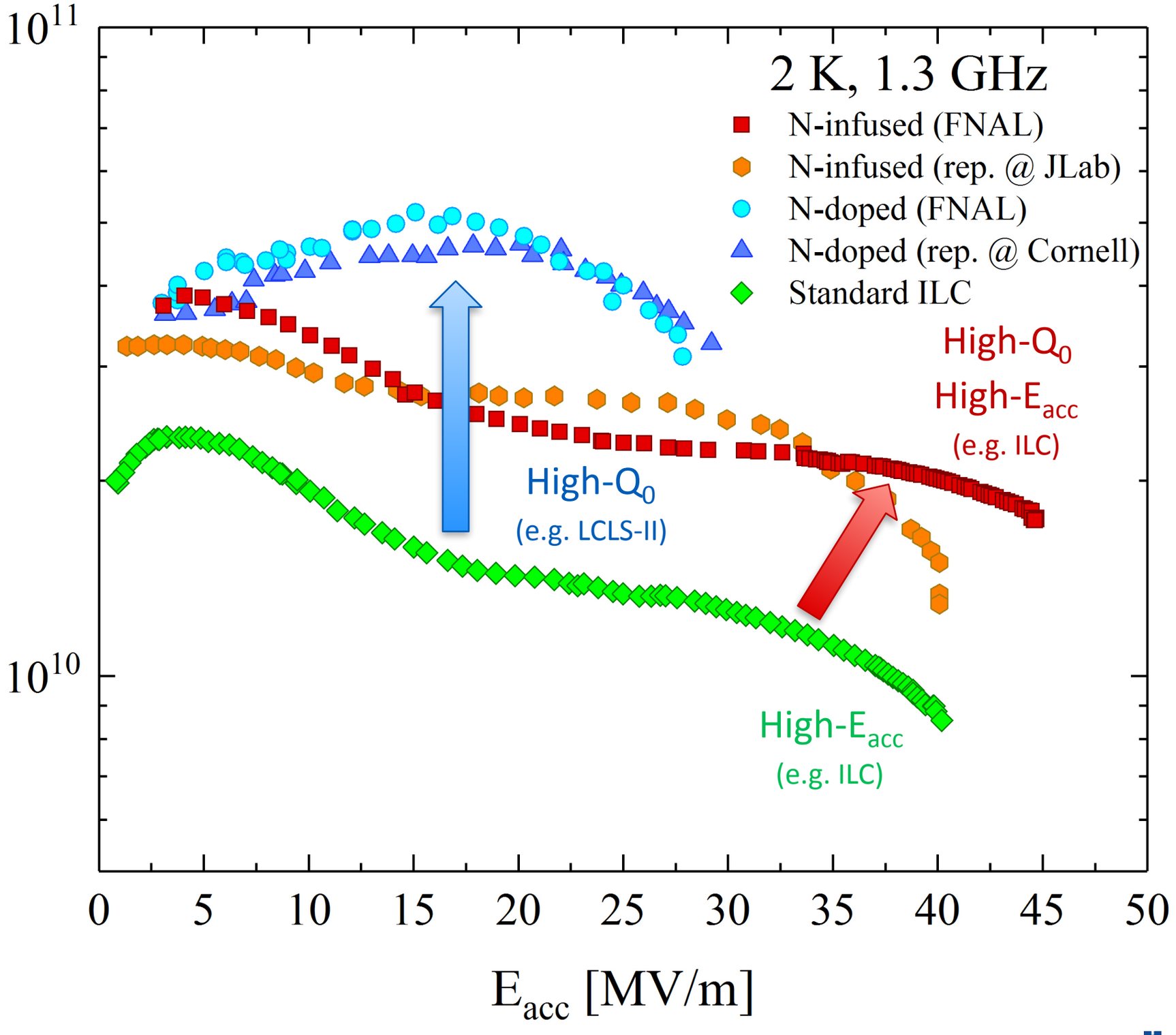
11

Also see talks by Phil Burrows (CLIC) and Jie Gao(CEPC) this workshop

Superconducting RF Development

- Remarkable Progress
  - *Increased Acceleration Gradient:*
    - Increased operating margins?
    - Higher energy at fixed tunnel length
  - *Increased Q*
    - Reduced thermal losses
    - Reduced cryogenics

State-of-the-art treatments

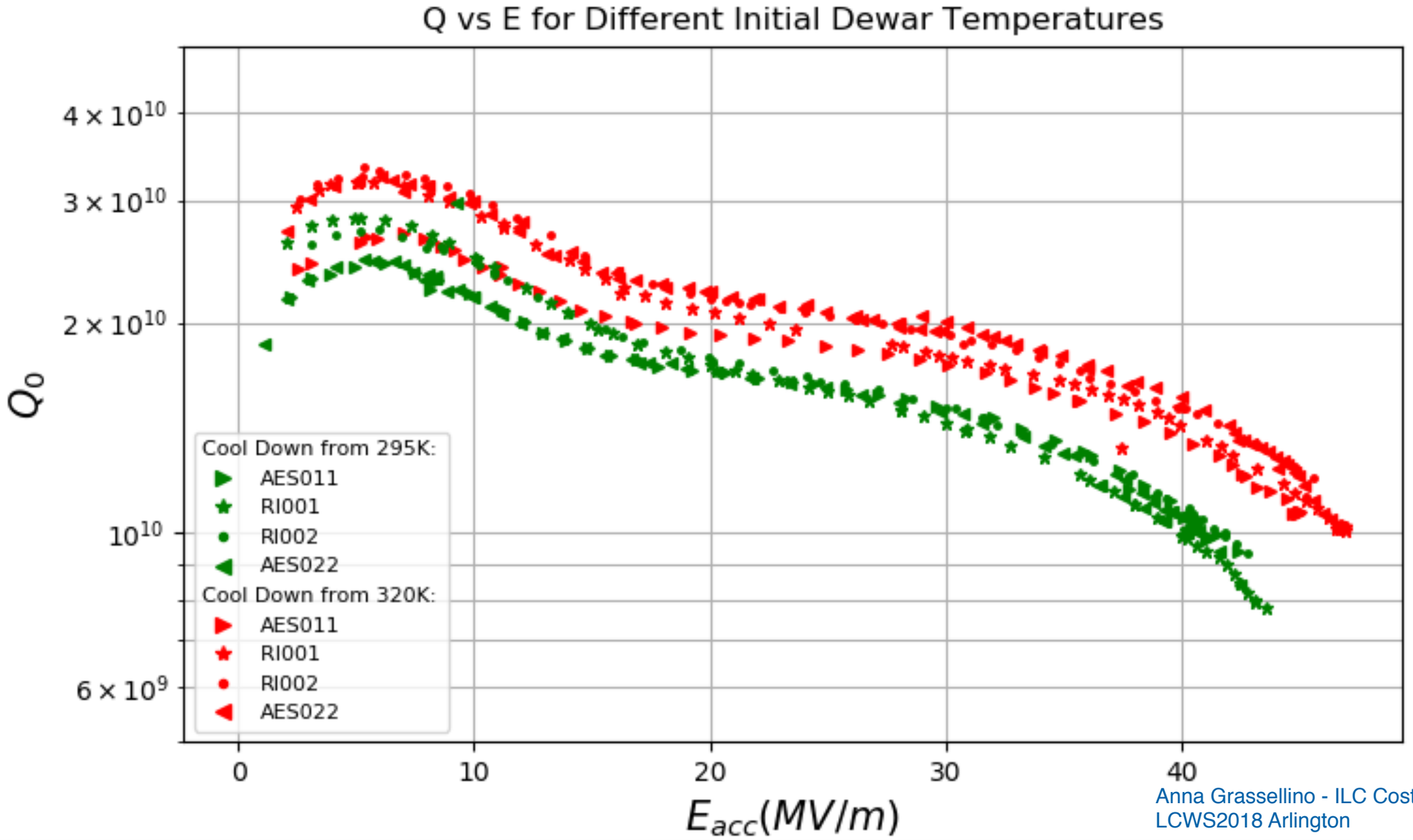


Fermilab

Improvements continue …

Anna Grassellino - ILC Cost Reduction

Grassellino, Bafia et al

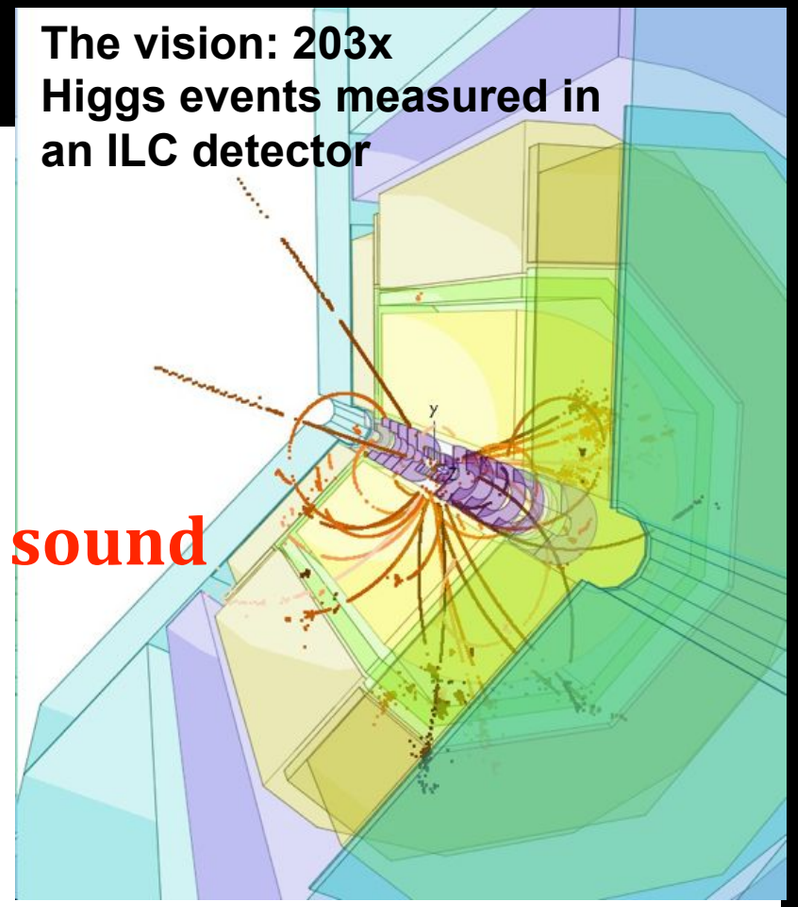


Anna Grassellino - ILC Cost Reduction

LCWS2018 Arlington

After being warmed in the dewar to 320-340K, performance improved from good to extraordinary (and remained stable for all subsequent cooldowns)

From J.Mnich this Workshop



- **Strong international support for the ILC**
  - **The next big collider after the LHC**
  - **Initially operating as Higgs factory**
- **Project is scientifically exciting and technically sound**
  - **Based on proven technologies**
  - **But a lot of technological and industrial challenges (accelerator and detector)**
- **High level political discussions in Japan**
  - **Community is waiting for a positive signal very soon to realise the ILC as international project under Japanese leadership**
- **We hope that high-level inter-governmental discussions on the ILC can start soon**
  - **Will require continuous enthusiasm and support from scientists and industrial partners**
- **2019 will be a decisive year for the ILC**

A Critical Moment for ILC

- After many years of analysis, design and preparation …
- With the benefit of a low-mass Higgs …
- In an environment with complementary/ competitive proposals but with strong international support …

Japan must make the next move! …

… and make it now.

Higgs Discovery to Higgs Factory

- LCWS 2012 was held in Arlington, soon after the July 4th Higgs boson discovery
- Six years later, LCWS is again in Arlington. (Thanks Andy White)
- The goal of the meeting is to take another step closer to the ILC becoming a Higgs boson factory.
- Hopefully at LCWS 2024(?) significant progress on ILC construction will be reported.

Texas Statement

October 24, 2018

- *The ILC is the right new experimental facility to advance our understanding of the Universe….*
- *The ILC is a source of new innovative technologies….*
- *Now is the time to move forward….*

Scientists attending LCWS2018 on behalf of the global Linear Collider Collaboration